Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/120111

A Control Chart for Time Truncated Life Tests Using Exponentiated Half Logistic Distribution

Gadde Srinivasa Rao

Department of Statistics, The University of Dodoma, Dodoma, PO. Box: 259, Tanzania

Received: 1 Apr. 2017, Revised: 5 Nov. 2017, Accepted: 10 Nov. 2017
Published online: 1 Jan. 2018

Abstract: In this article, an exponentiated half logistic distribution considered to develop an attribute control chart for time truncated life tests with known or unknown shape parameter. The performance of the proposed chart is evaluated in terms of average run length (ARL) using the Monte Carlo simulation. The extensive tables are provided for the industrial use for various values of shape parameter, sample size, specified ARL and shift constants. The advantages of the proposed control chart are discussed over the existing truncated life test control charts. The performance of the proposed control chart is also studied using the simulated data sets for industrial purpose.

Keywords: Exponentiated half logistic distribution; attribute control chart; truncated life test; average run length, simulation

1 Introduction

Control charts are powerful tools in statistical process control(SPC) to monitor the manufacturing process. To enrich the high quality of the manufactured products, to manufacture the product according to the given specifications and to reduce the inspection cost an intense monitoring of the production process is necessary. Hence, control charts are instrument to attain the high quality of products. In 1920s, W.A. Shewhart, introduced the control chart for the effective monitoring of the production process in the Bell Laboratories. A control chart contains three horizontal lines of which the central line (CL) represents the average value for the process in control while the other two horizontal lines called as upper control limit (UCL) and the lower control limit (LCL) are represented in such a way that whenever a process is in control almost all of the data points lie within these limits. The control charts can broadly study the variable characteristics and as well as attribute characteristics. The data that is based on qualitative characteristics or categories is known as attribute data and a chart which is used to monitor the attribute quality characteristic is called the attribute control chart such as *p*,*np* and *u* control charts. On the other hand, if the distribution of data is continuous we apply variable control charts and a chart which is used to monitor the variable characteristic of interest is called the variable control chart like *X-bar*, *R* and *S* control charts. The traditional Shewhart*np* control charts are the statistical control scheme most commonly used for monitoring the number of non-conforming items (see,[1]). A conforming category is one in which the products that fall within the control limits. A non-conforming category is one in which the products fall outside the control limits. As soon as the process shows an out-of-control alarm, the quality control engineers respond quickly and try to bring the production process in the state of the in-control. Due to its importance in the industry, many authors focused their attention to design various variable control charts.

Most of the control chart procedures have been developed under the assumption that the specific quality characteristic follows the normal distribution. There are instances when the form of the distribution of the quality characteristic is unknown or do not met the normal distribution. We notice that various researches focused on non-normal distributions control charts such as [2], [3], [4], [5] and [6]. In this article we propose the control chart scheme for time truncated life test using exponentiated half logistic distribution.

An attributes control chart, *p*-chart deals with the fraction of nonconforming or defective product produced by a manufacturing process. It is also called the control chart for fraction nonconforming. *np*-chart developed for the number of non-conforming products. Almost the same as the*p* chart, *c*- chart deals with the number of defects or

* Corresponding author e-mail: gaddesrao@yahoo.com

nonconformities produced by a manufacturing process. *u*-chart is meant for the nonconformities per unit produced by a manufacturing process. The control chart, though originally developed for quality control in manufacturing, is applicable to all sorts of repetitive activities in any kind of organization. They can be used for services as well as products, for people, machines, cost, and so on. For example, we can plot errors on engineering drawings, errors on plans and documents, errors in computer software as c or u charts. Sometimes, the quality control engineer has a choice between variable control charts and attribute control charts. The advantages of attribute control charts are allowing for quick summaries, that is, the engineer may simply classify products as acceptable or unacceptable, based on various quality criteria. Thus, attribute charts sometimes by pass the need for expensive, precise devices and time consuming measurement procedures. On the other hand, variable control charts are more sensitive than attribute control charts. Therefore, variable control charts may alert us to quality problems before any actual "unacceptable" (as detected by the attribute chart) will occur. [7] calls the variable control charts leading indicators of trouble that will sound an alarm before the number of rejects (scrap) increases in the production process. Many authors in the literature have worked on attribute control charts for example, [8], [9],[1] and [10].

In the fast developing world there are very high reliable products being produced in the industry. Since time is a main constraint, the testing process of these products is time taking as one has to wait until the complete testing time ends. So, to solve this problem we need to develop a control chart that is based on time truncated life test. By exploring the literature of attribute control charts, we found that not much work is done on *np* or *p* control chart under the time truncated life test. Recently [11],[12],[13],[14],[15] and [16] studied time truncated life test control chart for different distributions. Therefore, in this paper, we discussed the designing of the *np* control chart under time truncated life test when the lifetime of the product follows exponentiated half logistic distribution (EHLD). We determined the control chart constants and discuss the behavior of average run length (ARL) of the proposed control chart. The designing of the proposed control chart is presented (i) when the scale parameter is shifted and (ii) when the shape parameters are/ is shifted. Using simulated data, the industrial application of proposed *np* chart is illustrated. The rest of the paper is prepared as follows: a brief introduction about the exponentiated half logistic distribution is given in Section 2, the designing of the proposed control chart for EHLD is discussed in Section 3. A simulation study is presented in Section 4. Some concluding remarks are given in Section 5.

2 The Exponentiated Half Logistic Distribution

In this section we provide a brief review of the exponentiated half logistic distribution. Generalization or exponentiation of the base distribution was studied by different authors specifically with application of reliability [e.g. see [17], [18], [19]]. Exponentiated half logistic distribution is a generalization from half logistic distribution as suggested by [18]. More recently, [20,21, 22,23] studied exponentiated half logistic distribution in the area of reliability and quality control for the product lifetime percentiles. The cumulative distribution function (cdf) and the probability density function (pdf) of EHLD are respectively given by

$$F(t) = \left[\frac{(1-e^{-t/\sigma})}{(1+e^{-t/\sigma})}\right]^{\alpha} ; t \geq 0, \alpha > 0, \sigma > 0 \quad (1)$$

$$f(t) = \frac{2\alpha(1-e^{-t/\sigma})^{\alpha-1}}{\sigma(1+e^{-t/\sigma})^{\alpha+1}} ; t \geq 0, \alpha > 0, \sigma > 0 \quad (2)$$

where α is the Index parameter, σ is the scale parameter. When α=1, the EHLD becomes a half logistic distribution and its average is given by

$$\mu = \sigma\left[ln\left(\frac{1+0.5^{1/\alpha}}{1-0.5^{1/\alpha}}\right)\right] = \sigma\eta \quad (3)$$

where $\eta = ln\left(\frac{1+0.5^{1/\alpha}}{1-0.5^{1/\alpha}}\right)$.

3 Designing of proposed control chart

We propose the following *np* control chart under time truncated life test as designed by [14]:
Step 1: Take a sample of size n at each subgroup from the production process and put them on a time truncated life test. Count the number of failures (D, say) by the inspection time, $t = a\mu_0$, where μ_0 is the target average when the process is in control and a is a constant.
Step 2: Declare the process as out-of-control if $D > UCL$ or $D < LCL$. Declare the process as in-control, if $LCL \leq D \leq UCL$.
The process is said to be in-control when $\mu = \mu_0$ (or the scale parameter is $\sigma = \sigma_0$ and the shape parameters is $\alpha = \alpha_0$). The control limits for in control process are given as follows:

$$UCL = np_0 + L\sqrt{np_0\,(1-np_0)} \quad (4)$$

$$LCL = \max\left[0, np_0 - L\sqrt{np_0\,(1-np_0)}\right] \quad (5)$$

where p_0 is the probability that an item is failed before the experiment time t_0 when the process is in control. So, it is obtained from Equation (1) by

$$p_0=\left(\frac{1-e^{-t/\sigma_0}}{1+e^{-t/\sigma_0}}\right)^{\alpha_0}=\left(\frac{1-e^{-a\eta_0}}{1+e^{-a\eta_0}}\right)^{\alpha_0} \quad (6)$$

where $\eta_0=ln\left(\frac{1+0.5^{1/\alpha_0}}{1-0.5^{1/\alpha_0}}\right)$. In practice, probability p_0 is usually unknown, therefore, the control limits for the practical application are given as

$$UCL=\overline{D}+L\sqrt{\overline{D}\left(1-\overline{D}/n\right)} \quad (7)$$

$$LCL=\max\left[0,\overline{D}-L\sqrt{\overline{D}\left(1-\overline{D}/n\right)}\right] \quad (8)$$

where $\overline{D}$ is the average number of failures over the subgroups. The probability of declaring as in control for the proposed control chart is given as follows:

$$1p_{in}^{0}=P(LCL\leq D\leq UCL|p_0) \quad (9)$$

$$=\sum_{d=\lfloor LCL\rfloor+1}^{\lfloor UCL\rfloor}\binom{n}{d}\left(\frac{1-e^{-a\eta_0}}{1+e^{-a\eta_0}}\right)^{\alpha_0 d}\left[1-\left(\frac{1-e^{-a\eta_0}}{1+e^{-a\eta_0}}\right)^{\alpha_0}\right]^{n-d} \quad (10)$$

The efficiency of the proposed control chart is measured using the ARL. The ARL for in control process is given as follows:

$$ARL_0=\frac{1}{1-p_{in}^{0}} \quad (11)$$

3.1 ARL when scale parameter is shifted

The process is declared to be out-of-control when the process is shifted to a new scale parameter $\sigma_1=c\sigma_0$, where c is a shift constant. In this case, the probability that an item is failed before the experiment time t_0 denoted by p_1 , is obtained by

$$p_1=\left(\frac{1-e^{-t/\sigma_1}}{1+e^{-t/\sigma_1}}\right)^{\alpha_0}=\left(\frac{1-e^{-a\eta_0/c}}{1+e^{-a\eta_0/c}}\right)^{\alpha_0} \quad (12)$$

The probability of in-control for the shifted process is given as follows:

$$2p_{in}^{1}=P\left(LCL\leq D\leq UCL|p_1\right) \quad (13)$$

$$=\sum_{d=\lfloor LCL\rfloor+1}^{\lfloor UCL\rfloor}\binom{n}{d}\left(\frac{1-e^{-a\eta_0/c}}{1+e^{-a\eta_0/c}}\right)^{\alpha_0 d}\left[1-\left(\frac{1-e^{-a\eta_0/c}}{1+e^{-a\eta_0/c}}\right)^{\alpha_0}\right]^{n-d} \quad (14)$$

The ARL for the shifted process is given as follows:

$$ARL_1=\frac{1}{1-p_{in}^{1}} \quad (15)$$

We used the following algorithm to complete the tables for the proposed control chart.

(1) Specify the values of ARL, say R_0 and shape parameters α_0.
(2) Determine the values of control chart parameters and sample size n for which the ARL_0 from Equation (11) is close to R_0.
(3) Use the values of control chart parameters obtained in step 2 to find ARL_1 according to shift constant c using Equation (14).
We determined the control chart parameters and ARL_1 for various values of α_0, R_0 and n and placed in Tables 1-3. From these tables, we note that a rapidly decreasing trend in ARLs as the shift constant decreases.

3.2 ARL when shape parameter is shifted

In this section, we will present the designing of the proposed chart when the shape is shifted due to some extraneous factors. Let us assume that the shape parameter is shifted to $\alpha_1=\delta\alpha_0$ for a shift constant δ. In this case, the probability that an item is failed before the experiment time t_0, denoted by p_2, is obtained by

$$p_2=\left(\frac{1-e^{-t/\sigma_0}}{1+e^{-t/\sigma_0}}\right)^{\alpha_1}=\left(\frac{1-e^{-a\eta_1}}{1+e^{-a\eta_1}}\right)^{\delta\alpha_0} \quad (16)$$

where $\eta_1=ln\left(\frac{1+0.5^{1/\delta\alpha_0}}{1-0.5^{1/\delta\alpha_0}}\right)$.
The probability of in control for the shifted process is given as follows:

$$3p_{in}^{2}=P\left(LCL\leq D\leq UCL|p_2\right) \quad (17)$$

$$=\sum_{d=\lfloor LCL\rfloor+1}^{\lfloor UCL\rfloor}\binom{n}{d}\left(\frac{1-e^{-a\eta_1}}{1+e^{-a\eta_1}}\right)^{\delta\alpha_0 d}\left[1-\left(\frac{1-e^{-a\eta_1}}{1+e^{-a\eta_1}}\right)^{\delta\alpha_0}\right]^{n-d} \quad (18)$$

The efficiency of the control chart is measured using the ARL. The ARL for in control process is given as follows: The ARL for the shifted process is given as follows:

$$ARL_2=\frac{1}{1-p_{in}^{2}} \quad (19)$$

We determined the control chart parameters and ARL_2 for various values of α_0, R_0 and n and placed in Tables 4-8. From these tables, we note that the decreasing trend in ARLs as the shift constant δ decreases.

3.3 Application of proposed chart

The industrial application of the proposed control chart can be implemented as follows: Presume that the lifetime of an electronic equipment follows the exponentiated half

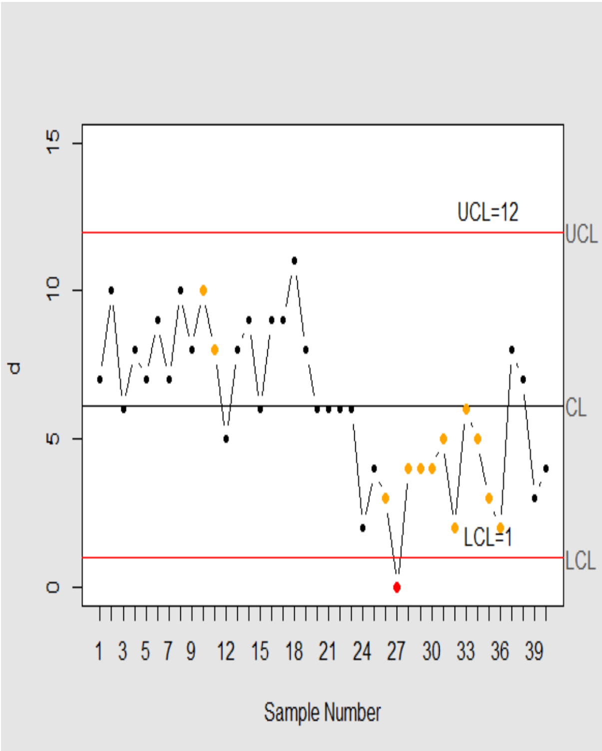

Fig. 1: The control chart for simulated data

Table 1: ARLs for the proposed chart for R_0=200 when scale parameter is shifted

α_0	1.0	1.5	2.0	2.5	3.0
n	42	40	47	42	47
LCL	11	4	13	11	13
UCL	29	20	32	29	32
a	0.986	0.653	0.982	0.972	0.985
K	2.8515	2.7745	2.9085	2.8330	2.9065
c	$ARL1$	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.00	200.01	200.00	200.01	200.00	200.00
0.90	64.48	68.12	35.14	39.92	23.28
0.80	15.02	14.28	5.17	5.26	3.16
0.70	4.21	3.75	1.57	1.55	1.21
0.60	1.68	1.50	1.04	1.03	1.00
0.50	1.08	1.04	1.00	1.00	1.00
0.40	1.00	1.00	1.00	1.00	1.00
0.30	1.00	1.00	1.00	1.00	1.00
0.20	1.00	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00	1.00

logistic distribution with shape parameter α_0=2. Assume that the target average life of electronic equipment is μ_0= 1000 hours and R_0= 370. Then from Equation (6) we have p_0= 0.3353. Also, from Table 4 we obtain the sample size of n= 32, a= 0.75, L= 3.0955, LCL = 2 and UCL = 18. Thus the inspection time t_0=750

Table 2: ARLs for the proposed chart for R_0=250 when scale parameter is shifted

α_0	1.0	1.5	2.0	2.5	3.0
n	39	50	26	45	45
LCL	5	12	3	0	6
UCL	22	32	17	13	24
a	0.684	0.908	0.824	0.500	0.798
K	2.999	2.981	2.828	3.237	2.923
c	$ARL1$	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.00	250.00	250.01	250.00	250.04	250.00
0.90	90.73	51.38	97.65	47.48	27.86
0.80	24.60	8.14	17.83	8.57	3.74
0.70	7.13	2.15	4.22	2.32	1.29
0.60	2.53	1.13	1.59	1.16	1.01
0.50	1.28	1.00	1.06	1.00	1.00
0.40	1.02	1.00	1.00	1.00	1.00
0.30	1.00	1.00	1.00	1.00	1.00
0.20	1.00	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00	1.00

Table 3: ARLs for the proposed chart for R_0=300 when scale parameter is shifted

α_0	1.0	1.5	2.0	2.5	3.0
n	31	15	48	27	55
LCL	6	1	11	5	6
UCL	22	12	31	20	26
a	0.899	0.972	0.904	0.951	0.753
K	2.9465	2.9565	2.9225	2.9180	3.0250
c	$ARL1$	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.00	300.00	300.01	300.00	300.02	300.00
0.90	175.23	109.33	61.63	106.46	21.66
0.80	45.01	32.81	7.46	14.97	2.92
0.70	11.51	10.32	1.85	3.29	1.16
0.60	3.51	3.72	1.06	1.35	1.00
0.50	1.50	1.71	1.00	1.02	1.00
0.40	1.04	1.12	1.00	1.00	1.00
0.30	1.00	1.01	1.00	1.00	1.00
0.20	1.00	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00	1.00

hours. Therefore, the proposed control chart works as follows:

Step 1: Take a sample of size 32 at each subgroup and put them on the life test during 750 hours. Plot the number of failed items (D) during the test.

Step 2: Declare the process as in-control if $2 \leq D \leq 18$ otherwise process as out-of-control.

4 Simulation study

In this section, the application of the proposed chart is discussed with the help of simulated data. The data are generated from exponentiated half logistic distribution when α=1.5 and σ=1. Let n=15 and R_0=300. It is declared that the process is in control when α=1.5 and

Table 4: ARLs for the proposed chart for R_0=370 when scale parameter is shifted

α_0	1.0	1.5	2.0	2.5	3.0
n	38	46	32	23	46
LCL	7	11	2	1	11
UCL	25	31	18	15	31
a	0.845	0.932	0.750	0.841	0.957
K	3.0750	3.0455	3.0955	3.0645	3.0965
c	$ARL1$	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.00	370.02	370.01	370.00	370.02	370.00
0.90	132.87	87.54	60.94	59.92	34.96
0.80	30.76	12.53	11.01	11.16	4.01
0.70	7.81	2.83	2.87	2.99	1.30
0.60	2.54	1.24	1.29	1.34	1.01
0.50	1.26	1.01	1.01	1.03	1.00
0.40	1.01	1.00	1.00	1.00	1.00
0.30	1.00	1.00	1.00	1.00	1.00
0.20	1.00	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00	1.00

Table 5: ARLs for the proposed chart for R_0=300 when shape parameter is shifted from α_0=2

n	41	49	54	45
LCL	24	28	5	3
UCL	40	46	25	21
a	1.589	1.515	0.691	0.676
K	3.0905	3.0445	2.9975	3.0245
δ	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.0	300.02	300.01	300.01	300.03
0.9	172.72	177.72	189.65	191.55
0.8	95.89	99.87	113.14	116.10
0.7	51.52	54.02	65.41	68.26
0.6	26.87	28.34	37.07	39.32
0.5	13.69	14.53	20.72	22.30
0.4	6.92	7.38	11.49	12.51
0.3	3.59	3.83	6.38	7.00
0.2	2.03	2.15	3.63	3.98
0.1	1.36	1.42	2.21	2.40

Table 6: ARLs for the proposed chart for R_0=370 when shape parameter is shifted from α_0=2

n	37	46	38	47
LCL	0	26	20	4
UCL	13	44	36	23
a	0.484	1.525	1.491	0.703
K	3.5405	3.1235	3.1600	3.0885
δ	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.0	370.01	370.03	370.04	370.01
0.9	273.62	214.11	238.54	247.22
0.8	142.38	119.04	144.36	154.76
0.7	64.87	63.93	83.31	93.13
0.6	28.93	33.26	46.17	54.52
0.5	13.14	16.86	24.68	31.22
0.4	6.23	8.43	12.80	17.54
0.3	3.18	4.28	6.56	9.73
0.2	1.83	2.34	3.47	5.41
0.1	1.26	1.50	2.05	3.13

Table 7: ARLs for the proposed chart for R_0=300 when shape parameter is shifted from α_0=3

n	41	44	27	44
LCL	0	0	0	3
UCL	13	15	12	21
a	0.552	0.593	0.638	0.740
K	3.3520	3.1435	3.3925	3.0107
δ	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.0	300.02	300.02	300.01	300.03
0.9	187.23	157.13	247.29	206.29
0.8	95.60	79.63	172.22	135.40
0.7	45.57	39.88	106.60	85.78
0.6	21.47	19.95	61.48	52.69
0.5	10.25	10.07	33.93	31.39
0.4	5.06	5.20	18.13	18.11
0.3	2.67	2.83	9.45	10.11
0.2	1.59	1.69	4.85	5.49
0.1	1.14	1.18	2.56	2.98

Table 8: ARLs for the proposed chart for R_0=370 when shape parameter is shifted from α_0=3

n	52	50	55	49
LCL	31	32	7	23
UCL	49	48	28	43
a	1.468	1.571	0.789	1.259
K	3.156	2.9665	3.0665	3.0525
δ	$ARL1$	$ARL1$	$ARL1$	$ARL1$
1.0	370.04	370.02	370.04	370.04
0.9	231.81	234.70	278.13	277.93
0.8	134.66	131.24	194.87	198.82
0.7	74.09	68.04	129.50	135.97
0.6	38.94	33.50	82.44	88.89
0.5	19.62	15.85	50.43	55.35
0.4	9.54	7.32	29.58	32.60
0.3	4.56	3.42	16.58	18.00
0.2	2.28	1.75	8.85	9.28
0.1	1.34	1.15	4.59	4.62

Table 9: The simulated data

$S.No.$	D	$S.No.$	D	$S.No.$	D	$S.No.$	D
1	7	11	8	21	6	31	5
2	10	12	5	22	6	32	2
3	6	13	8	23	6	33	6
4	8	14	9	24	2	34	5
5	7	15	6	25	4	35	3
6	9	16	9	26	3	36	2
7	7	17	9	27	0	37	8
8	10	18	11	28	4	38	7
9	8	19	8	29	4	39	3
10	10	20	6	30	4	40	4

σ=1. The first 20 observations of subgroup size 15 are generated using in control parameters. Now, suppose that the process has shifted due to the shift in the scale parameter of exponentiated half logistic distribution. Let c= 0.7. The next 20 observations are generated with shifted scale parameter when α=1.5 and σ=0.7. The data are reported in Table 9.
The life test termination time be t_0=0.972x1.4826=1.44. The number of failures D are counted and reported in Table 9 for each subgroup. The average number of failures $\overline{D}$ is computed. The UCL=12 and LCL=1 is for simulated data. The data is plotted in the Figure 1. From Figure 1, it can be seen that the proposed chart show the shift at 27th observation (7th observation after the shift) while tabulated ARL is 10. So the proposed chart efficiently detects the shift in the process.

5 Concluding remarks

In this article, we proposed a new np control chart assuming that the lifetime of the product follows to exponentiated half logistic distribution. The chart constants and for the industrial use extensive tables are presented. The methodology explained with the help of simulated data. We note the decreasing trend in ARLs values. The proposed control chart can be used in the industries for monitoring of non-conforming products such as the mobile phone charger and computer hard disk. The proposed control chart can be extended for some other distributions as a future research.

Acknowledgement

The authors are grateful to the anonymous referee for a careful checking of the details and for helpful comments that improved this paper.

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Gadde Srinivasa Rao is Associate Professor of Statistics at University Dodoma, Tanzania. He received the PhD degree in Statistics at Acharya Nagarjuna University, Guntur, India. He is referee of several international journals in the frame of Reliability and Quality control. His main research interests are: statistical inference, statistical process control, acceptance sampling plans and reliability estimation. He has published more than 80 research articles in different peer-reviewed reputed international journals.